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AN OVERVIEW OF DREV'S ACTIVITIES ON PULSED CO_2 LASER TRANSMITTERS: FREQUENCY STABILITY AND LIFETIME ASPECTS

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SUMMARY

After introducing the desired features in a transmitter for laser radar applications, the output characteristics of several configurations of frequency-stable TEA-CO_2 lasers are reviewed. Based on work carried out at the Defence Research Establishment Valcartier (DREV), output pulses are examined from short cavity lasers, CW-TEA hybrid lasers, and amplifiers for low power pulses. It is concluded that the technique of injecting a low-power laser beam into a TEA laser resonator with Gaussian reflectivity mirrors should be investigated because it appears well adapted to producing high energy, single mode, low chirp pulses. Finally, a brief report on tests carried out on catalysts composed of stannic oxide and noble metals demonstrates the potential of these catalysts, operating at close to room temperature, to provide complete closed-cycle laser operation.

INTRODUCTION

This overview summarizes several investigations and developments carried out at DREV on pulsed CO_2 laser radar transmitters intended for use in coherent detection laser radar systems. With these systems the functions of ranging, velocity measurement and angle tracking are being investigated on hard targets such as airplanes, helicopters and missiles. Many of the pulsed atmospheric sensing lidars, planned or being developed throughout the world for land or space operation, require a transmitter with essentially the same performance characteristics as those sought for our hard-target laser radars.

The output and lifetime characteristics desired in a transmitter will now be discussed, taking into consideration the variety of applications being considered. For the types of targets and ranges involved, pulse repetition rates of up to 100 Hz and pulse energies of approximately 1 J are of the greatest interest. Output pulse lengths varying from 50 ns to 2 μs are suitable for our applications. The longer pulses are more appropriate for measuring velocity from the Doppler frequency shifts, the shorter pulses for precise range measurements. With a monostatic laser radar configuration, a pulse with a short tail (e.g. $\leq$ 2 μs) is preferable for making measurements at close ranges (e.g. $\leq$ 1 km) because of the backscatter generated on the optical components by the outgoing transmitter pulse. Especially for transmitters with the longer output pulses, our objective is to maintain both the pulse to pulse and intrapulse frequency instability to $\leq$ 1 MHz. More precisely, the frequency chirp rate should be low enough that it is the pulse envelope shape and not the total frequency chirp which determines, at low signal-to-noise ratios, the velocity resolution limit. Also, a laser pulse with a short tail generates less total frequency chirp for a given chirp rate. Finally, to be practical the ideal transmitter should have a closed-cycle gas recirculation system, or have a very low gas consumption. This paper will review some of DREV's activities on closed-cycle, frequency stable, CO_2 laser transmitters.

THE IMPORTANCE OF FREQUENCY STABILITY

Most of DREV's recent experience with pulsed coherent laser radars has been acquired from the Infrared Ranging and Tracking System (IRATS) (ref. 1). The transmitter for this system was a CW-TEA hybrid laser operating at the 10.6-μm wavelength. With this particular transmitter configuration, laboratory measurements indicated that the frequency of the output pulse swept over 8 MHz between the 1-μs and 4-μs points of the pulse. To a Doppler frequency processing unit, this frequency chirp in the return signal appears as a target velocity which varies from 0 m/s to 45 m/s over a distance of 450 m. For the case of a single pulse return, determining the target's range and velocity is relatively straightforward provided the characteristics of the transmitted pulse are known. The signal processing problem becomes much more serious with multiple target returns or the returns from a distributed target such as the atmosphere. In conclusion, for our planned applications, the use of a transmitter with low frequency chirp would undoubtedly facilitate Doppler frequency processing.

FREQUENCY STABLE LASER SOURCES

Over the past years numerous methods have been investigated for generating a single longitudinal mode (SLM) in a TEA-CO_2 laser cavity. As could be expected, the configurations suited to SLM operation were not always well adapted to high energy pulses, high frequency stability or low-divergence transverse modes. This paper will review work at DREV on short-resonator lasers, hybrid lasers and the amplification of low power pulses.

Short, Stable Resonator Laser

Short cavity lasers were first investigated at DREV using a miniature TEA-CO_2 laser which had an 18-cm-long stable resonator, a 1 cm × 1 cm × 10 cm discharge volume, a 7.5-mm diameter iris to limit the oscillation to the fundamental transverse mode, and a piezoelectric transducer to tune the cavity length (ref. 2). At a gas pressure of 400 torr and the properly tuned cavity length, SLM operation was achieved. The 15-mJ output pulse had a 45-ns spike and a 2-μs tail. When the pulse was mixed with the output of a CW laser and heterodyne detected on a HgCdTe photodiode, it was determined that the laser pulse had a chirp rate of 1.7 MHz/μs^2. This TEA laser was also studied when frequency stabilized from pulse to pulse with a feedback loop to apply corrections to the cavity length. For this stabilization, the frequency of each heterodyne detected pulse, measured with a gated counter, was used to produce an error signal to correct the length of the cavity for the next laser pulse. It was found that the long-term frequency drift in the output pulses was eliminated and the measured beat frequency from pulse to pulse had a standard deviation of 500 kHz.

With this type of laser, the limited dimensions of the discharge volume are a major obstacle to producing high energy pulses. With an increased discharge length SLM operation is no longer possible, and with a greater discharge cross section it is not practical to maintain the fundamental transverse mode output.

In summary, this short stable resonator laser produced short frequency stable pulses, which had significant chirp, a low output energy, and a pulse to pulse frequency instability of 500 kHz.

Short Cassegrain Resonator with Gaussian Reflectivity Mirrors

To overcome the drawbacks of the standard short cavity lasers, DREV has supported investigations on the use of Gaussian reflectivity mirrors in a Cassegrain resonator to produce a fundamental mode of large cross sectional area (ref. 3). A Gaussian reflectivity mirror is a mirror whose reflectivity varies as a Gaussian function across the diameter of the mirror. For the investigation the test laser with a 50-cm long optical cavity had a 2 cm × 2 cm × 30 cm TE-CO_2 gain module at a gas pressure of 375 torr. The Cassegrain resonator configuration using Gaussian reflectivity mirrors had a magnification of 1.2. For comparison purposes, this laser was also modified and studied with a conventional "hard" mirror Cassegrain configuration and a stable resonator. It was found that in a full-angle beam divergence of 1.3 mrad (i.e. 2.44 λ/d with d = 2 cm), the encircled energy in the far field was, as a ratio to the 175 mJ total energy, 0.7 for Cassegrain Gaussian mirrors, 0.3 for the Cassegrain hard mirrors, and 0.03 for the stable resonator. With proper tuning of the cavity length, the 70-ns output pulse from the Gaussian mirror did not show the mode-beating which was present with the two other tested resonator configurations. The lack of mode-beating indicated that with the Gaussian mirrors the problem of transverse mode selection in unstable resonators had been overcome and that single longitudinal mode operation had been achieved. By beating the pulse from the Gaussian mirror laser with the output from a CW laser, the chirp rate in the pulse was measured at 60 kHz/μs^2.

The significantly lower chirp measured with the Gaussian mirror laser is the result of having a large laser mode diameter (ref. 4). Also, the large mode diameters which are possible with this unstable mode configuration can produce relatively high output energies with short cavity lengths and relatively low power densities on the laser mirrors.

It can be concluded from this work that a laser having a short Cassegrain resonator with Gaussian reflectivity mirrors can produce short, frequency stable pulses, with low chirp and interesting output energies. Although not measured, a pulse to pulse frequency instability of 500 kHz would be expected. This laser configuration can produce an output with almost all the desired characteristics except for the pulse length which is rather short for many applications involving velocity measurements.

Hybrid CW-TEA Laser

Two experimental laser radar systems developed a DREV (refs. 1 and 5) have used a hybrid laser transmitter because of this transmitter's relative simplicity and output pulse length which is suited to Doppler frequency measurements over a period of > 1 μsec. The laser transmitter for IRATS (ref. 6) had a 1 cm × 1 cm × 30 cm TEA discharge section and a 50-cm-long low-pressure CW tube which were mounted in a

130-cm-long resonator. An iris (≃ 0.9 cm) was required inside the cavity to limit operation to the fundamental transverse mode. The output pulse energy was 80 mJ at a 100 Hz pulse repetition rate.

This laser was frequency stabilized in the following manner. The length of the laser resonator was modulated with a voltage applied to a piezoelectric transducer, the output from the CW-CO_2 laser section was mixed with a local oscillator laser on a high-speed detector, and the resulting swept IF frequency was sent to a frequency selector. When the frequency selector detected the desired IF frequency, the TEA-CO_2 laser discharge was triggered and the resulting high power laser pulse was emitted at close to the same IF frequency. Most of the energy in this long-tailed pulse is present in the first 2 μs. The intrapulse chirp was measured at 0.89 MHz/μs^2. With the above stabilization technique the pulse-to-pulse frequency difference between the transmitter and the local oscillator had a standard deviation of 50 kHz. Without the cavity length modulation and the feedback loop in operation the pulse-to-pulse frequency instability was 500 kHz.

In conclusion, we have found that the hybrid CW-TEA laser can produce long, frequency stable pulses which have relatively high-frequency chirp, energies of a few hundred millijoules, and high pulse to pulse stability. It was also found that, because of the time it takes for the gain of the CW tube to re-establish after each TEA-CO_2 pulse, the maximum pulse repetition rate achievable with this type of laser is about 300 Hz. Although this laser configuration has many merits, it does have relatively high chirp and a limited output energy because of the restrictions on the beam cross-sectional area.

Pulse Amplification

Pulse amplification has been investigated (ref. 7) by passing the output of a miniature TEA laser (a short cavity stable resonator configuration) through a three pass TEA amplifier arranged in an off-axis Cassegrain configuration. For the laboratory mesurements each TEA laser pulse was heterodyne detected and recorded both before and after amplification. By comparing the unamplified and amplified pulses it was concluded, to a first approximation, that neither the average pulse frequency nor the intrapulse frequency characteristics have been significantly altered by amplification. However, it was noted that the amplitude of the pulse tail had been decreased upon amplification. The pulse energies were about 1 J at the output of our amplifier.

Our work has shown that pulse amplification can produce frequency stable pulses of > 1 J/pulse. The amplified pulse has appreciably unaltered frequency characteristics but its length is reduced. This investigation was not extended to studying the effects, on the pulse length reduction, of varying the delay between the amplifier's excitation current and its injected signal, or of changing the pulse shape of the amplifier's excitation current.

CATALYSTS IN TEA-CO_2 LASERS

About 10 years ago DREV supported the industrial development of a 300-Hz TEA-CO_2 laser which used a hot platinum catalyst to reduce gas consumption. Although this type of catalyst was very effective, unacceptable amounts of power were required to heat the catalyst and then cool the laser gas after it had been in contact with the hot catalyst. More recently, catalysts consisting of stannic oxide and noble metals have been prepared (ref. 8) and tested in our laboratories.

The activity of the different SnO_2 catalysts was compared by introducing 30 torr of CO and 15 torr of O_2 into a 1-liter test cell containing a given amount of the catalyst under test. The rate of the reaction $2CO + O_2 \rightarrow 2CO_2$ was monitored with measurements of both the gas pressure and the infrared absorption of CO_2 at 15.9 μm.

In our evaluation it was found that a 2% Pt - SnO_2 catalyst was efficient but that up to 2 or 3 times greater activity could be obtained with 2% bimetal or trimetal catalysts (e.g. Pt-Pd, Pt-Rh, Pt-Pd-Rh).

With the catalyst powder contained in the hollow centers of sintered stainless-steel filter elements, the evaluation was extended to actual tests in a miniature TEA-CO_2 laser. With no forced gas circulation in the laser it was found that 5 gms of catalyst were required to maintain the laser's output energy at 90% of its original value at a pulse repetition rate of 1 Hz. No testing of the catalyst has yet been carried out in a high-repetition-rate laser with forced gas flow.

DISCUSSION

This paper has reviewed some of DREV's work on closed-cycle, frequency-stable TEA-CO_2 lasers. It has been shown that each laser configuration has certain advantages and limitations. To develop a frequency stable transmitter having output energies of > 1 J/pulse, a low-frequency chirp rate, and a long output pulse, it is believed that a technique consisting of injecting a low-power laser beam (ref. 9) into a Cassegrain resonator with Gaussian reflectivity mirrors should be investigated. The injection technique could produce single-longitudinal-mode pulses of 1-μs to 2-μs duration and the Gaussian reflectivity mirrors would eliminate unwanted transverse modes. The large discharge cross section used in the unstable resonator configuration would yield the high energy pulses with low frequency chirp. Also, the cavity mirrors are subjected to lower energy densities.

Closed cycle gas operation using acceptable quantities of a SnO_2 catalyst was first reported for a 100-Hz pulse repetition rate laser in 1983 (ref. 10). With the present effort at several laboratories, it is expected that the addition of catalysts to TEA-CO_2 lasers will become standard technology in all but experimental lasers.

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